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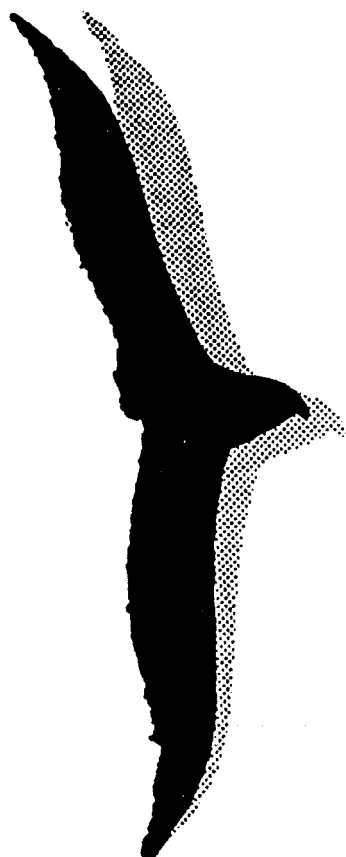
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a simulation model approach

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The effects of transaction costs and human capital on firm size: a simulation model approach

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Abstract

Differences in optimal firm size may only be explained by heterogeneity amongst enterprises and the markets in which they operate. Therefore, the concept of the representative enterprise from the traditional theory of the firm is not helpful in explaining size differences. Differences in firm size may better be explained using recent developments in **labour** economics that stress the heterogeneity of workers and enterprises. In this paper, we exploit these new developments in **labour** economics by building a simulation model of the firm, which explicitly considers the link between internal and external **labour** markets and the resulting worker flows. Simulations with the model show how factors that account for differences in transaction costs and for heterogeneity of workers generate enterprises of different sizes.

Keywords: firm size, transaction costs, human capital, internal **labour** market, **labour** flows.



SCALES

Scientific **AnaLysis** of Entrepreneurship and **SMEs**

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1. Introduction

Traditional neo-classical microeconomic theory, based on the concept of the representative firm, cannot explain why firms differ in size. Economies of scale, resulting from technical and allocational efficiency, can explain cross-industry differences in average firm size. It does, however, not explain the size distribution of firms found in the real world. Other theories have been developed to explain the vast heterogeneity in firm size. Three alternative approaches to explain firm size may be distinguished (You, 1995). According to the transaction cost approach (or institutional approach), firm size is determined by transaction cost efficiency*. Within the industrial organization approach, size distribution is explained by market power. Thirdly, the growth approach focuses on the dynamics of the size distribution of firms. This approach includes life-cycle models and evolutionary models on firm growth. The relevance of these approaches has been examined in a number of empirical studies. For example, Davis and Henrekson (1999) have examined the role of institutions in explaining national differences in firm size distribution, and Almus and Nerlinger (1999) combined elements from the neo-classical and growth approach to explain growth of new technology-based enterprises.

Recently, another possible determinant of firm size has received the attention of economic research: labour flows. Analysis of large longitudinal datasets at enterprise level has provided much insight into the specific characteristics of labour flows between enterprises and establishments, and their connection with labour market dynamics (Davis and Haltiwanger, 1990,1992; Davis et al., 1996). A major finding is that the largest part of job turnover (job creation + job destruction) takes place within the same regions and branches of industry. It implies that job creation and job destruction are much more driven by idiosyncratic, firm-specific shocks than by demand and supply shocks at macro level. Another finding is that worker flows exceed job flows. For the Netherlands, Hamermesh et al. (1996) find that worker turnover is roughly three times as large as job turnover.

Differences in firm size are likely to affect worker turnover and internal labour flows, and vice versa. From that perspective, this study examines the relation between firm size and internal labour flows. In doing so, we combine literature on labour flows with the standard neo-classical and transaction cost approaches to explain firm size. For this purpose, we construct an empirical simulation model that incorporates various mechanisms that may be regarded as underlying sources of firm heterogeneity. Although firm behaviour is described by profit maximization, building and solving an analytical model that incorporates all required sources of heterogeneity appeared impossible. Therefore, we were forced to recourse to a simulation model that is calibrated using the scarce empirical evidence on internal labour flows (Van Gasteren, 2000). In this paper, we investigate in what manner this combination of theories explains firm size differences.

2 From a macroeconomic point of view, transaction costs include costs associated with existing institutions. Transaction cost theory then effectively becomes an institutional theory of the firm (You, 1995, page 448).

The content of the paper is as follows. The next section reviews what the literature on transaction costs, hierarchical models of the firm, equilibrium search theory and internal labour markets can teach us about the underlying sources of heterogeneity amongst enterprises. This gives us a hint on how to make this heterogeneity operational in the model. Section 3 discusses how these features are implemented in the simulation model. Next, we identify the various characteristics of firm size distribution that we shall examine with this model. The simulation outcomes are presented and discussed in sections 5 and 6. Section 7 concludes.

2. Theoretical background

Transaction costs

Adam Smith stated that **firm** size is determined by benefits and costs of specialization of **labour**, resulting in economies of scale. The degree of specialization would be limited mainly by the extent of the markets. Coase (1937) examined whether this specialization should take place within one single firm, or between several enterprises. He introduced the idea of transaction costs, to explain which transactions should take place in the market, and which transactions are more efficient within the framework of an enterprise. Transaction cost theory assumes that all transactions are costly due to bounded rationality and opportunism. We adopt the concept of transaction costs to incorporate the cost of an enterprise's internal organization in our simulation model.

A transaction is any transfer of goods or services **from** one individual to another. Transactions can take place either within or between firms; in this paper we focus on transactions within firms, and, therefore, on internal transaction costs. All transactions require coordination and cooperation from the individuals involved; hence, transaction costs can be classified into coordination and motivation costs (Milgrom and Roberts, 1992). Internal coordination consists of several steps (each resulting in internal coordination costs): obtaining information needed to determine an efficient plan for a transaction; using the knowledge available to determine the plan to be implemented; communicating the plan to those responsible for implementing it; and monitoring the plan. Motivation cost may arise due to information incompleteness, information asymmetries and imperfect commitment (resulting in hold-up problems). Nooteboom (1993) and Gamsey (1998) argue that small businesses have a behavioural advantage over large enterprises, in that employees in smaller businesses are more motivated. This results in higher motivation costs (per employee) for larger enterprises.

These transaction costs refer to costs of vertical transactions: transactions that involve different hierarchical levels within an enterprise. However, transactions may also take place within a certain level. Becker and Murphy (1992) argue that both horizontal coordination and motivation cost per employee increase with the number of employees.

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3 Assuming that employers want to maximize their profits

Hierarchical models of the firm

Williamson (1967) used a hierarchical model of an individual enterprise to examine determinants of optimal firm size⁴. This model delineates a price-taking enterprise with m administrative levels. Each employee may supervise s subordinates, i.e. the span of control equals s . Williamson also introduced a ‘compliance’ or ‘loss of control’ parameter that indicates the effective contribution of an employee to the objectives of his supervisor. The compliance parameter is less than 1, reflecting that ‘only a fraction of the intentions of the superior is effectively satisfied by a subordinate’ (Williamson, 1967). Without loss of control, the enterprise would have an infinite number of levels; in effect, its size would be limited by the size of the market only.

The loss-of-control parameter in this model may be interpreted as a measurement for vertical internal transaction costs. This interpretation becomes clear when we explore Williamson’s argument to introduce the loss of control. The intentions of the supervisor will never be fully satisfied because either the communication between supervisor and subordinate is imperfect, or because subordinates do not follow up on agreements made. The first explanation reflects (vertical) coordination costs, the second motivation costs. Williamson’s (1967) conclusion that the compliance parameter must be less than 1 for enterprises to become finite is, therefore, similar to the conclusion by Coase (1937) that firm size is finite due to positive (internal) transaction costs.

Becker and Murphy (1992) argue that optimal firm size is related to the degree of specialization and coordination costs *within* hierarchical levels. In their model, individual production increases with team size. This is because larger teams allow for more specialization. The benefits of specialization are balanced with the increasing costs of coordination between a larger number of more specialized workers. They find that under some general conditions, team size is limited by coordination costs instead of market size.

Equilibrium search and internal labour markets

An objective for our simulation model is that it should outline the dynamic time path of the enterprise in response to various types of external shocks. Therefore, the actual firm size should continuously be adapted to its optimal size, taking account of adaptation costs (e.g. costs of hiring, firing and training). So as to outline this dynamic adjustment process, the model combines insights of modern equilibrium search models and the flow approach of the labour market (see Mortensen and Pissarides, 1998) with insights from internal labour market models (Doeringer and Piore, 1971). These theories also explicitly take worker heterogeneity into account. This is another feature that our model incorporates.

3. Internal labour flows in a hierarchical model of the firm

Our simulation model focuses on formalizing decisions of personnel managers as regards the allocation of employees over the jobs available. The model specifies hierarchical levels in line with Williamson (1967), and applies the theory developed by Becker and Murphy (1992) to model benefits and costs of cooperation within

⁴ This model has later been augmented by Calvo and Wellisz (1978) and Keren and Levhari (1979).

teams/levels. This allows us to endogenize the span of control, which is exogenous in Williamson (1967). In this section, we outline the specification and calibration of the models.

Independent decisions

The key assumption in our hierarchical model is that each employee decides whether he or she spends time on the production of output or on supervising subordinates (or on a combination of both) independently from others in the enterprise. Under specific conditions, this yields identical results as when all decisions are centralized. We consider this decision for each individual to be taken by the management of the business rather than by employees themselves.

Benefits of specialization

Optimization starts with the highest-ranked person in the enterprise. He determines the optimal number of subordinates for his circumstances by maximization of his contribution to the business's profits, weighting the costs and benefits of recruiting additional subordinates. The benefits consist of the production generated by the subordinates. We specify individual production functions, based on the quality of the employee. If more subordinates are recruited, the tasks that must be performed and coordinated by the supervisor may be divided over a larger group of subordinates. This results in specialization of the subordinates, which yields an increased individual productivity. A subordinate's contribution to firm production is, therefore, modelled as a function of individual productivity and the number of subordinates within his team.

Horizontal and vertical transaction costs

However, increasing the number of subordinates also increases horizontal transaction costs (both coordination and motivation). We assume that the horizontal transaction costs per subordinate rise with the number of subordinates (Becker and Murphy, 1992). The combined effect of specialization and horizontal coordination results in a parabolic relation between the profits of the supervisor and the number of subordinates. Individual productivity may benefit from cooperation with other subordinates (of the same supervisor) at the same hierarchical level; however, hiring too many subordinates turns the cooperation into a negative factor when specialization is extended too far.

The model also incorporates vertical transaction costs. These are the sum of foregone production and loss of control. Foregone production measures the time a supervisor has to spend on supervising and coordinating the subordinate; while coordinating, he cannot contribute to production. The amount of coordination required by a subordinate depends negatively on his qualities. Loss of control measures the extent as to which, even after coordination, subordinates still will not be able/willing to produce the output required by their supervisor. Besides horizontal and vertical transaction costs, the costs of subordinates depend on their wages.

⁵ The model is presented in the appendix. It is a variant of the model developed by Van Gasteren (2000). We refer to his study for further details.

Finite firm size

Coase (1937) concluded that enterprises have a finite size due to positive transaction costs. This is also the case for our model: in the absence of any transaction costs, firm size is limited by the size of the market only (which is infinite, since we assume perfect competition). Transaction costs are necessary to ensure both a finite number of hierarchical levels and a finite team size.

When the enterprise has reached its optimal size, marginal profits become zero and additional subordinates are no longer beneficial. In other words, the production technology is **modelled** in such a way that after a certain point, the supply curve becomes upward sloping (due to decreasing returns to scale).

Adjustment costs

Until now, we discussed the costs and benefits of *having* subordinates. A major feature of our model is that it contains costs for *changing* the number of subordinates as well. Adjustment costs arise if the optimal number of subordinates differs from the actual number. We identify three types of adjustment costs. In the case of superfluous employees, the employees having the lowest qualities are fired. The firm must pay firing costs for each fired employee. If the enterprise has a staff shortage, it has to fill vacancies by searching for suitable employees. The enterprise searches, first, among the employees currently employed in other jobs at the business. We assume the supervisor has insight in the qualities of the employees in the next lower rank in the hierarchy (perfect information). Second, if the capacities required are not available within the enterprise, the supervisor may decide to recruit a new employee. This necessitates an external search procedure that bears a higher cost level. External applicants (i.e. their age and quality) are drawn **from** a random distribution; the enterprise has no influence on the arrival of candidates. This mimics, in a way, incomplete information. If a candidate fails to meet the minimum requirements, a training procedure can be considered, at a certain cost. A possible outcome of the (external) application procedure is that the job remains vacant.

Operation of the simulation model

Optimization of the profits of the entrepreneur and his search for subordinates – the mechanisms of which are both discussed above – are the first two steps in the operation of the simulation model. The third step is that for each filled job, *i.e.* for each subordinate, we repeat the optimization and search procedure, by taking into account the central assumption: each employee takes independent decisions on whether he works on the production of output, on the supervision of subordinates, or a combination of both. The optimal number of subordinates is independent from the decisions made at other ranks and in other branches in the hierarchy: it is (modelled as) a purely individual decision. As outlined above, we **modelled** the structure of the profit **function** and the level of the transaction costs ‘in such a way that they set a limit on firm **size**. Under this condition, the number of repetitions of steps 1 and 2 is finite, and it is possible to delineate the enterprise by number of employees, organizational structure, generated output and number of unfilled vacancies (step 4 in table 1). Notice that both the number of hierarchical ranks and the number of subordinates per team are **endogenous** in the model.

After steps 1 to 4, we obtain the hierarchical set-up of the enterprise at the onset of a period. All workers in the hierarchy remain at their jobs for (at least) one period and produce output during this period. The passing of time generates an increase in the experience of employees within the enterprise (‘learning by doing’), which is implemented as an increase in their personal measure of quality. The effect depends on the tenure in the current job and has a random component. At the end of the period, a random number of employees decide to quit the company. Here, we may think of workers who find jobs elsewhere, or workers who have other reasons to leave the **labour** force. A fraction of the employees will retire; we impose a mandatory retirement age. Furthermore, employees may get dismissed if their qualities do not meet minimum requirements. This is possible only for employees who were recruited at the beginning of the period, and needed a training course to enhance their qualities. If that training doesn’t lift their quality levels to minimum requirements they will be dismissed. The result of quits, retirements and fires is the opening of vacancies at the old positions. Instead of immediately searching for candidates who may fill these vacancies (and the unfilled vacancies remaining from the previous search process), we return to the optimization process (step 1) to determine whether it is optimal to search for employees to fill the vacancies, or whether it is best to close the vacancies altogether. The next steps in the modelling algorithm are conducted successively, as outlined above.

Table 1 Set-up of the simulation model

STEP 1	Determination of optimal number of subordinates (per supervisor, per time period)
STEP 2	In the case of vacancies: search for employees <ul style="list-style-type: none"> o Promotion of insiders (causes vacancy chains) o Recruitment of outsiders (training might be necessary) In the case of superfluous workers: dismiss the least qualified subordinates (the result of this step might be that there remain unfilled vacancies)
STEP 3	Perform steps 1 and 2 for each subordinate until reaching the rank where the (optimal) number of subordinates equals zero
STEP 4	Determine the number of employees, production (optimal, actual), hiring, firing, (flows, cost) and organizational structure of the enterprise
STEP 5	<ul style="list-style-type: none"> o Random quits will occur o There will be an increase in the experience of the employees who stay (‘learning by doing’) o Repeat steps 1 to 4 for the following period

Calibration of the model

The parameters of the model are calibrated upon the scarcely available empirical evidence. Our baseline calibration generates a benchmark representative firm whose flow characteristics (quits, fires, and internal and external worker flows) mimic the results found in a study by Hamermesh *et al.* (1996). This study presents estimates of the annual worker flows in the Netherlands in 1990, drawn from a stratified sample of about

1,000 enterprises with 10 or more employee&. The selection of the model parameters, to generate our benchmark firm, is based on case studies on the internal economics of enterprises by Baker et al. (1994) and Van **Gameren** et al. (1999). Both case studies utilize personnel records of a large enterprise, and **specify** how the internal structure such as the span of control and the wage scales of the business are organized. The calibration of search costs is based on linear approximation of the quadratic adjustment cost function of Pfann and Verspagen (1989). Their results suggest that in the **case of** small adjustments, recruitment cost seem to be somewhat higher than the firing costs, while for more expansionary firms, hiring costs increase exponentially. We assume that external search is more expensive than internal search, which implies that the first option to fill vacancies is through internal moves.

Simulation results with our calibrated model of a representative business are shown in table 2. The flows are based on simulations over 50 periods (or **years**)⁷, and replicated 100 times to account for the random processes incorporated in the model. Averages are taken over the last 25 years since during the initial years, the business grows to its optimal size. The simulation results can be compared with the results of Hamermesh et al. (1996) that are presented in the column ‘target size’.

Table 2 indicates that average firm size hardly fluctuates between the various simulations: the standard deviation of the number of employees is small. A closer inspection of the simulation results provides insights into the hierarchical structure. The employer hires four employees (say heads of units or plants). Each of these employees wants to hire five subordinates (say heads of branches), and is eventually able to keep these positions filled each period. These subordinates (20 in total) also want to hire five employees each, but they are not always able to keep these positions occupied (due to quits, retirements or dismissals, and the absence of internal candidates). It is only at this lowest level that the simulated enterprises show any variation in number of employees. Apparently, the heterogeneity between enterprises (quality, age and tenure of employees) is not large enough to change the optimal number of subordinates and levels between enterprises.

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⁶ **Allaart** et al. (2000) use a more recent data set for the Netherlands (concerning 1996). and find very similar worker flow estimates.

⁷ In the model, a period is defined as a year. This facilitates both the modelling of the ageing of employees, and the calibration using estimates of annual flows.

Table 2 Simulation results*

Type and direction of worker flows	Simulation results		Target size
	mean	standard deviation	
Number of employees in the firm	123	1.90	136
Inflow			
Hire to a newly created job (%)	2.0	1.70	3.2
Hire to an existing job (%)	7.8	3.39	8.7
Outflow			
Quits/retirements (%)	7.6	2.97	8.2
Direct fires (%)	1.9	1.53	
Outflow from a destroyed job (%)	0.35	0.66	1.9
Internal mobility			
To a newly-created job (%)	0.04	0.24	1.2
To an existing job (by direct subordinate) (%)	0.2	0.51	2.2
To an existing job (from other team) (%)	2.2	1.82	

* The target sizes are taken from Hamermesh *et al.* (1996), table 1, with the exception of the number of employees in the **firm**, which is taken from Van **Gameren** (2000), table 6.3. All percentages denote percentages of employment. The sample standard deviations are calculated over the last 25 periods.

The table shows that the random processes that hit the enterprise cause more variation in some of the **labour** flows than in **firm** size. Our calibrated benchmark model is able to reproduce the target values with respect to the inflow and outflow of employees reasonably well. Its distribution of total outflow over outflow from existing jobs (quits/retirements and direct **fires**⁸) and outflow from destroyed jobs seems less successful. Jobs are being destroyed (the annual job destruction rate is 1.2%), but most employees whose jobs are destroyed can find employment elsewhere in the enterprise. It is, however, important to notice that the target sizes taken from Hamermesh *et al.* (1996) represent a growing business: total inflow (11.9%) exceeds total outflow (10.1%). Our calibrated benchmark model represents a business in equilibrium, with constant firm size, and inflow and outflow being equal. Hamermesh *et al.* (1996) find that the dismissal rate (both direct fires and outflow from destroyed jobs) is lowest for enterprises with constant employment level, which suggests that the target size for outflow from a destroyed job is set too high.

Target values for internal flows are the most difficult to reproduce in the calibration procedure. Internal mobility towards new jobs is very low: once a business has stabilized, new jobs are almost exclusively created at the lowest rank in the hierarchy (where vertical mobility is, by definition, not possible). Vacancies that arise at higher levels are mostly filled by internal mobility; external inflow occurs almost exclusively at the lowest rank.

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⁸ Direct fires occur, when employees are tired because their qualities are insufficient. These employees directly leave the **firm**, whilst their jobs remain intact. Indirect fires occur when jobs are destroyed; these employees can apply for vacancies elsewhere in the **firm**.

4. Firm size distributions

The size distribution of a population of firms may be described by various characteristics. Our simulation model enables us to examine the following features?

- (i) The average size of firms that survive for a certain number of years: the model allows for the possibility that enterprises do not survive after 50 years, either because the original owner cannot find a successor, or because at a certain point all employees leave the business. Average firm size is taken over all surviving enterprises.
- (ii) The survival rate: the fraction of all simulated firms that survive after 50 years.
- (iii) The average start-up length: the length of the start-up period is determined by the first year in which the business reaches a size of at least 95% of the average size (for the scenario in table 2, the start-up length is 4 years).
- (iv) The within-standard deviation of firm size: a measure of the average standard deviation within each firm, over all periods of time: it indicates how the same firms differ in size over time.
- (v) The between-standard deviation of firm size: a measure for the difference in average firm size between enterprises: it indicates how different firms differ in size at the same time.

To examine these characteristics of firm size distribution, the simulation model combines elements from various approaches to explaining firm size. The relevance of the neo-classical (or microeconomic) and transaction cost approaches have been examined before (You, 1995). Elements from these approaches that are incorporated in the model are the relevance of **labour** productivity, wage costs, costs and benefits of specialization and vertical transaction costs (loss of control and costs of supervision). Equilibrium search theory is represented by random quits of employees, search costs, and requirements for internal and external candidates. Finally, to take account of the relevance of human capital of individual employees, the simulation model allows for variation in the qualities of external candidates, and (variation in the effects of) learning by doing and firm-provided training.

The following two sections examine the relevance of these approaches by assessing their impact on the five size distribution characteristics. Section 5 focuses on the microeconomic and transaction cost approaches, by studying the impact of changes in **labour** productivity and costs and benefits of specialization on firm size and **labour** flows. In section 6, the working of the neo-classical mechanisms and the effect of transaction costs is compared with the relevance of search theory and (heterogeneous) human capital of individual employees for the size distribution of firms.

5. Labour productivity, specialization and firm size

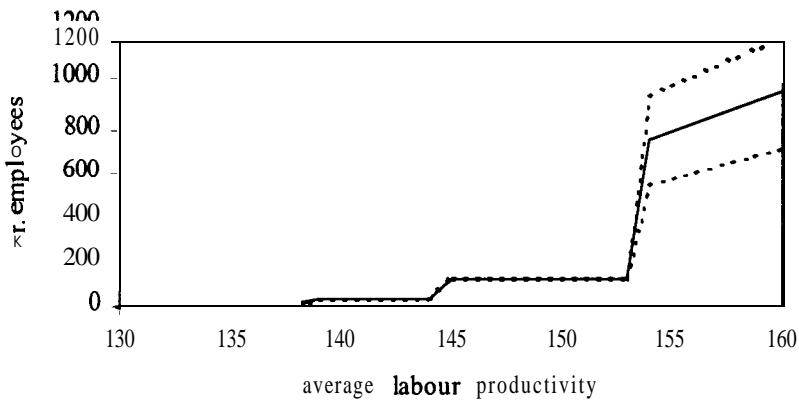
Labour productivity and firm size

Our first simulation examines the impact of changes in average **labour** productivity (the annual production of a new employee with average quality). The calibration dis-

⁹ With the exception of the survival rate, all characteristics are calculated over the last 25 periods.

cussed in the previous section resulted in a business with an average **labour** productivity of 150 units a year (with the price of a unit of production normalized to 1). Figure 1 shows the relation between average **labour** productivity and firm size. If average **labour** productivity is too low and does not cover (transaction) costs, entrepreneurs don't recruit any employees, and enterprises do not survive **after** 50 years. At a certain threshold point¹⁰, **labour** productivity becomes high enough to make it profitable to recruit employees, and a level is added to the firm. The survival rate of enterprises now suddenly shifts to 100%.

Figure 1 Relation between **firm** size and average **labour** productivity*



- The dotted lines represent average **firm** size $\pm 2 \times$ the standard deviation of **firm** size.

Firm size increases only if productivity becomes high enough to add a third level to the firm, and later on a fourth level”. Changes in average **labour** productivity have no effect on the size of the teams. Additional profits from increased productivity are not large enough to justify the costs of increased horizontal and vertical coordination that are associated with an expanding team size.

This changes however, if average productivity is increased further. A small increase at the next threshold point (from 155 to 156) now has two effects. An additional level is added to the firm, which increases average firm size. Moreover, firms now differ also in the sizes of their teams. Not only at the **fifth** level, but at all levels of the hierarchy. Variation in team size increases with hierarchical level. This results in a large variation in firm size. Beyond this threshold point, average firm size is determined by team size, and not so much by the number of hierarchical levels (for example: increasing the average production level **from** 155 to 160 raises average firm size, whilst the number of hierarchical levels remains the same).

This intriguing change in the working of the model may be explained as follows. All stochastic elements in the simulation model are related to the human capital of individual employees: qualities of new applicants, returns to training, effects of learning ^{*by doing} and voluntary quits (voluntary quits result in a loss of human capital, and open an opportunity to gain new human capital). It is, therefore, the heterogeneity in

¹⁰ At an average **labour** productivity of 136; this value depends on the other parameter values.

¹¹ At an average **labour** productivity of 139 and 145, respectively.

the human capital available that causes the variation in firm size. Two combined effects make this mechanism work in large enterprises in particular. Below, we explain why.

Human capital influences marginal costs of production

A supervisor will hire employees as long as marginal benefits of the additional *production* exceed marginal costs. The marginal benefits of an additional unit of production are by definition equal to output price, which is normalized to 1. The marginal costs consist of marginal wage costs and marginal transaction costs (supervision costs and adjustment costs). We assume marginal productivity wages: wages per output are independent of human capital. In contrast, supervision costs per unit of output are negatively related to the amount of human capital: more human capital implies both higher production and lower supervision costs¹². To conclude: human capital influences marginal costs of additional production and, therefore, - in theory - the decision on how many employees to hire.

This finding also explains why the variation in team size increases with the hierarchical level. This is because with each additional level, transaction costs (which depend on human capital available) increase relative to wage costs. With each additional level, the costs of managing the hierarchical firm become more **important**¹³.

Human capital influences marginal costs and benefits of employees

Another way of analyzing the recruitment decision is to compare marginal costs and benefits of recruiting an additional *subordinate*¹⁴. Due to the costs and benefits of specialization, both marginal costs and marginal benefits depend on the number of incumbents.

The human capital of (incumbent) workers influences both marginal costs and marginal benefits of an additional subordinate. Whether this actually affects the (discrete) recruitment decision, depends on how strong marginal costs and benefits depend on the number of incumbent workers and on their human capital. Our simulations show that average **labour** productivity must exceed a certain threshold before human capital actually affects firm size.

Specialization and firm size

Firm size is determined by the number of workers within each team, and the number of hierarchical levels. Williamson (1967) **modelled** the number of workers within each

¹² The marginal adjustment costs of an additional unit of production are also negatively related to human capital, but less strong than marginal supervision costs. This is because adjustment costs are independent of human capital.

¹³ This is not a consequence of the structure of the model, but of the calibration process (see appendix). Different values for the parameters that determine transaction costs could result in different conclusions.

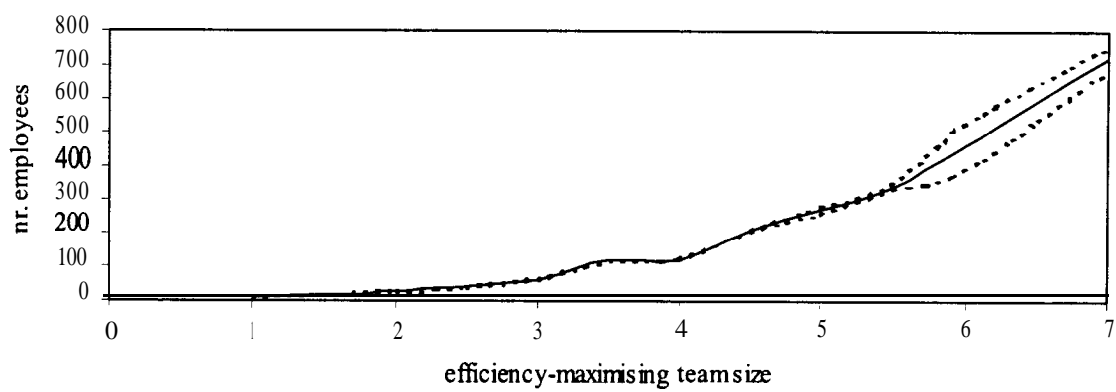
¹⁴ Both the number of subordinates within a team and the number of hierarchical levels are determined by equating the marginal costs and benefits of recruiting an additional subordinate (the number of hierarchical levels may be found by deriving at which level it is optimal to recruit zero subordinates). In the appendix, an equation is derived for this problem. As in the model by Williamson (1967), this equation can only be solved numerically.

team as an exogenous variable: the span of control. In his model, increasing the span of control resulted in an increase in the number of levels, so that the effect on firm size is twofold.

Instead, the span of control is endogenized in our model by introducing (the costs and benefits of) specialization. The net contribution of an individual to the total production of its team is the difference between the benefits of specialization and the costs of horizontal coordination. This combined effect is modelled as a parabolic relation, along the lines of Becker and Murphy (1992). Hence, we have an endogenous span of control determined by the efficiency-maximizing team size (defined as the number of employees for which the average net contribution per employee is maximal). This efficiency-maximizing team size may be manipulated by simultaneously changing costs

Figure 2 the relation between firm size and the efficiency-maximizing team size.

Figure 2 the relation between firm size and the efficiency-maximizing team size.



Note: the dotted lines represent the average firm size $\pm 2 \times$ the standard deviation of firm size.

and benefits of specialization.

Increasing the efficiency-maximizing team size from 1 to 7 employees increases the average firm size from 4 to more than 700 employees (see figure 2). This is exactly according to the expectations of the traditional microeconomic approach: economies of scale (or specialization) have a positive impact on firm size. Contrary to Williamson (1967), we find that increases in the efficiency-maximizing team size have no effect on the number of hierarchical levels.

The efficiency-maximizing team size is independent of wage and transaction costs. As a result, the simulated (profit maximizing) team size is not equal to the efficiency-maximizing team size. In fact, the simulated team size differs between hierarchical levels (since transaction costs differ between levels). With the exception of the highest level, the simulated team size is larger than the efficiency-maximizing team size.

6. Different approaches to explaining firm size distribution

This section examines the effects of changes in several model parameters, for both a small (25 employees) and a large (600 employees) benchmark firm. These parameters

represent elements of the various approaches to explain firm size distribution: the technical approach (wage costs, benefits of specialization), transaction cost approach (costs of specialization, loss of control and supervision), equilibrium search theory (search costs, requirements for candidates, quit rate) and human capital of individual employees (variation in qualities of external candidates, effects of learning by doing and training).

Simulating small and large enterprises

The small firm is simulated by selecting the value for average productivity. This yields an enterprise with three levels, with approximately 25 employees (see table 3). The large enterprise is simulated by enhancing average productivity so that profit maximization yields an enterprise with five levels. Adding a fifth level results in higher standard deviations of firm size, both within and between enterprises (see table 4). Simulation experiments show that this effect does not only occur when average labour productivity is enhanced: changes in other parameters may also result in large enterprises with five levels and high within-/between-standard deviations.

The average rates of in- and outflow are comparable for small and large enterprises: inflow is 9% of total employment for small and 11% for large enterprises. The difference is caused by the difference in average quit rates between small and large enterprises (because the quit rate differs between hierarchical levels, large enterprises have *ceteris paribus* higher quit rates). The nature of the flows differs, however. For small businesses, the majority of inflow concerns existing jobs, whilst for large enterprises it is mostly inflow into newly created jobs. There are fewer fires in large than in small businesses. The outflow from destroyed jobs is very similar.

Table 3 Simulation results for a small benchmark firm

Type and direction of worker flows	Average	Within-standard deviation	Between-standard deviation
Survival rate	99%		
Start up length (years)	4		
Number of levels	3	0	0
Number of employees in the firm	24.5	0.72	0.16
Inflow			
Hire to a newly created job (%)	1.8	0.67	0.11
Hire to an existing job (%)	7.2	1.29	0.25
Outflow			
Quits/retirements (%)	6.4	1.22	0.14
Direct fires (%)	2.3	0.74	0.16
Outflow from a destroyed job (%)	0.4	0.29	0.05
Internal mobility			
to a newly-created job (%)	0	0.02	0.00
to an existing job (by direct subordinate) (%)	0.6	0.40	0.01
to an existing job (from other team) (%)	1.0	0.50	0.03

The internal mobility is clearly higher for large enterprises as they have more opportunities for job movers than small businesses have. This is due to the larger pool of

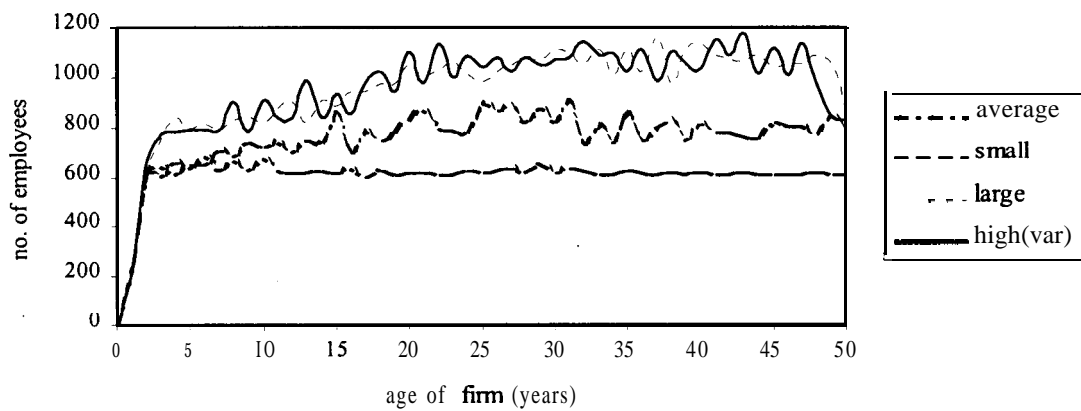
incumbent workers with sufficient qualifications. This result is in accordance with the findings of Hamermesh *et al.* (1996) and Hassink (1996).

Table 4 Simulation results for a large enterprise

Type and direction of worker flows	Within-standard		Between-standard
	Average	deviation	deviation
Survival rate	99%		
Startup length (years)	19		
Number of levels	5		
Number of employees in the firm	792	44.2	93.9
<i>Inflow</i>			
Hire to a newly created job (%)	8.6	48.2	25.4
Hire to an existing job (%)	2.4	15.7	16.0
<i>Outflow</i>			
Quits/retirements (%)	9.3	9.3	8.5
Direct tires (%)	0.9	5.0	1.0
Outflow from a destroyed job (%)	0.6	13.1	2.7
<i>Internal mobility:</i>			
to a newly created job (%)	3.5	21.6	18.6
to an existing job (by direct subordinate) (%)	0.1	0.8	0.3
to an existing job (from other team) (%)	9.4	16.5	27.4

Figure 3 illustrates the variance in firm size for the large enterprise, both within individual businesses over time (measured by the withinstandard deviation) and between enterprises (measured by the between-standard deviation). It shows the development of four different simulated firms: a firm with an average within-deviation, the firm with the highest within-deviation, and the firms with - on average - the most and least employees. It is clear from figure 3 that the number of employees often changes; this is also reflected in table 4 by the fact that variation in inflow (and internal mobility) far exceeds the variation in outflow rates.

Figure 3 Four different 'large' enterprises



Allaart *et al.* (2000) have calculated worker flows for different size classes. This enables us to compare our simulation outcomes with some empirical information. Al-

laart *et al.* (2000) find that in- and outflow of workers vary less with size class than internal flows do. Particularly for enterprises with 20-49 employees they find that in-flow equals 12.5% of the number of employees, outflow 10.5% and internal flow 2.3%. For enterprises with more than 500 employees, these volumes are 12.6%, 11.1% and 6.9%, respectively. These results are comparable with Hassink (1996), who finds internal **labour** flows of 2.4% for businesses with less than 100 employees, and 4.9% for enterprises with more than 100 employees. Our model reproduces the (small) difference in outflow between small and large enterprises rather well, but it underestimates internal mobility for small businesses, and overestimates internal mobility for large enterprises.

Sensitivity analysis

By way of sensitivity analysis, our final set of simulation experiments illustrates the influence of parameter changes on size distribution of firms and on **labour** flows. These parameter changes represent various options for changing the performance of the business. They may be associated with the various theoretical approaches to explain heterogeneity amongst enterprises, which are combined in the model. The aim of these simulations is to give some indication, both in the case of a small business and of a large enterprise, of the relative impact (on firm size) of various ways in which enterprises may adapt their production process, internal organization and personnel management. Simulations are conducted with the following parameter changes:

- (i) Wage cost: these cost are defined by two parameters, *viz.* *wagc*, representing the wage at the highest hierarchical level and *wagl*, representing wage differences between the hierarchical levels. It should be noted that a change in *wagc*, given *wagl*, implies a change of all wages in the business. Also, since product price is fixed and the model assumes completely elastic product demand, a change of wage costs of the enterprise should be interpreted as a **firm-specific** change and may not be considered the consequence of a general wage restraint or wage push.
- (ii) Specialization: costs and benefits of specialization are represented by two different parameters.
- (iii) Vertical transaction costs: here, the model includes 3 parameters which represent various types of vertical transaction costs, *viz.* the loss-of-control parameter, indicating how much supervision is needed per subordinate, and two parameters which determine foregone production due to supervision (*fgpc*, representing the costs at the highest hierarchical level, and *fgpl*, representing cost differences between the hierarchical levels).
- (iv) Search cost: external and internal search costs have been altered proportionally, as both costs have the same influence on the working of the model.
- (v) Search requirements: here, changes in three parameters are considered, *viz.* in the 'baseline' minimum requirements *reqc* (the minimum requirements at the highest hierarchical level), the differences in requirements between hierarchical levels *requl*, and the additional minimum requirement for an internal applicant, *rqie*. Given the average human capital of external applicants, lowering the requirements enhances the probability of finding a suitable applicant, but lowers the average quality of employees. Increasing additional minimum re-

quirements for internal applicants enhances the average quality of those who are promoted but decreases internal mobility.

- (vi) Quit rate: the probability that employees decide to leave the enterprise, for other reasons than retirement.
- (vii) Average human capital: here, changes may occur due to a change in the average quality of external applicants (*pdfu*) or a change in the effects of learning by doing and training (*grwe*).

Tables 5 and 7 show the effect on the characteristics of the size distribution of the firms and on labour flows's, when the parameter changes represent an increase in the performance of the business: Tables 6 and 8 show the effect of opposite changes in these model parameters.

As the response of our model to various shocks and parameter changes is highly non-linear, mainly as a consequence of ratchet effects (change of number of levels), it appears that in some cases, small businesses react less strongly to changes than large enterprises do. Therefore, we have conducted our simulation experiments with larger parameter changes for the small business (tables 5 and 6) than for the large enterprise's (tables 7 and 8).

Table 5 Changing parameter values to stimulate performance of small businesses

	bench mark	Wages		Specialization		Vertical transaction costs		
		wagc	wagl	benefits	costs	loss of control	fgpc	fgpl
		-5%	-2.5%	+2.5%	-5%	-1%	-10%	-2.5%
Survival	99%	100%	99%	100%	99%	100%	100%	100%
Size (nr. empl)	24.5	24.5	122.9	123.8	151.0	122.7	122.9	122.8
Within st.dev.	0.7	0.7	1.8	2.3	4.8	1.7	1.5	1.5
Between st.dev.	0.2	0.1	0.4	0.7	6.1	0.3	0.3	0.3
Inflow	9.0%	9.0%	9.8%	9.7%	9.5%	9.8%	9.8%	9.9%
Internal mobility	1.6%	1.5%	2.4%	2.5%	4.5%	2.3%	2.0%	2.0%
		Search costs	reqc	Search reql	requirements rqie	Quit rate	Human capital pdfu	grwe
		-10%	-35%	-25%	-50%	-2%pt	+30%	+75%
Survival	99%	100%	100%	100%	100%	100%	100%	100%
Size (nr. empl)	24.5	122.1	24.5	24.4	24.5	24.6	24.5	24.6
Within st.dev.	0.7	1.7	0.7	0.7	0.7	0.6	0.7	0.7
Between st.dev	0.2	0.3	0.2	0.2	0.1	0.1	0.2	0.1
Inflow	9.0%	9.7%	7.1%	6.8%	9.2%	5.8%	7.7%	8.5%
Internal mobility	1.6%	2.6%	3.3%	3.7%	1.6%	1.6%	2.3%	1.8%

¹⁵ Since our model represents firms in equilibrium, outflow and inflow rates are virtually identical. We therefore only present the inflow rates in our tables.

¹⁶ For example: for large firms, the parameter on the effects of learning by doing and training (grwe) was changed with +/- 10% (tables 7 and 8). For small firms, this change had no effect. Instead, tables 5 and 6 report the effects of changes of +/- 75%.

Table 6 Changing parameter values to hamper performance of small businesses

	bench mark	Wages		Specialization		Vertical transaction costs		
		wagc	wagl	benefits	costs	loss of control	fgpc	fgpl
		+5%	+2.5%	-2.5%	+5%	+1%	+10%	+2.5%
Survival	99%	100%	100%	100%	100%	100%	100%	99%
Size (nr. empl)	24.5	4.8	4.9	4.9	4.8	4.9	4.9	24.4
Within st.dev.	0.7	0.4	0.4	0.4	0.4	0.4	0.4	0.7
Between st.dev.	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Inflow	9.0%	9.5%	9.2%	8.6%	9.8%	9.8%	9.1%	9.2%
internal mobility	1.6%	1.5%	1.5%	1.4%	1.5%	1.4%	1.4%	1.7%
		Search costs	reqc	Search requirements reql	rqie	Quit rate	Human capital pdfu	grwe
		+10%	+35%	+25%	+50%	+3% pt	-30%	-75%
Survival	99%	100%	6%	49%	69%	99%	68%	57%
Size (nr. empl)	24.5	4.8	23.4	3.8	24.4	24.0	23.6	24.2
Within st.dev.	0.7	0.4	1.2	1.4	0.8	1.0	1.1	0.9
Between st.dev.	0.2	0.1	0.4	0.7	0.1	0.2	0.3	0.2
Inflow	9.0%	9.9%	13.0%	31.3%	9.3%	18.3%	15.6%	12.4%
Internal mobility	1.6%	1.5%	1.6%	3.7%	1.4%	2.4%	2.1%	5.0%

Table 7 Changing parameter values to stimulate performance of large enterprises

	bench mark	Wages		Specialization		Vertical transaction costs		
		wagc	wagl	benefits	costs	loss of control	fgpc	fgpl
		-2.5%	-2.5%	+2.5%	-2.5%	-0.5%	-5%	-2.5%
Size (nr. empl)	792	884.6	1020.8	1176.3	1171.6	849.7	837.9	848.6
Within st.dev.	44.2	44.7	47.3	30.9	29.1	44.9	44.5	40.8
Between st.dev.	93.9	112.5	115.3	1.9	40.5	59.9	99.1	97.2
Inflow	11.0%	10.7%	10.6%	10.6%	10.5%	10.9%	10.9%	10.8%
Internal mobility	13.0%	14.2%	12.0%	7.9%	7.6%	14.7%	14.3%	14.5%
		Search costs	reqc	Search requirements reql	rqie	Quit rate	Human capital pdfu	grwe
		-5%	-10%	-10%	-10%	-2% pt	+10%	+10%
Size (nr. empl)	792	849.6	801.0	817.7	796.5	910.8	809	845
Within st.dev.	44.2	42.9	44.0	46.5	43.4	43.0	44.5	47.0
Between st.dev.	93.9	107.0	97.7	108.6	86.2	34.3	72.0	42.1
Inflow	11.0%	10.8%	10.7%	10.0%	10.9%	4.2%	10.6%	11.0%
Internal mobility	13.0%	15.7%	14.1%	14.6%	13.7%	12.2%	14.4%	17.5%

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Table 8: Changing parameter values to hamper performance of large enterprises

	bench mark	Wages		Specialization		Vertical transaction costs		
		wagc	wagl	benefits	costs	loss of control	fgpc	fgpl
		+2.5%	+2.5%	-2.5%	+2.5%	+0.5%	+5%	+2.5%
Size (nr. empl)	792	709.8	122.7	122.2	609.8	123.6	779.5	123.3
Within st.dev.	44.2	34.3	1.6	1.6	4.2	2.2	43.1	2.1
Between st.dev.	93.9	95.7	0.3	0.4	0.7	0.5	88.7	0.6
Inflow	11.0%	10.8%	9.9%	9.8%	10.5%	9.9%	10.9%	9.8%
Internal mobility	13.0%	10.3%	2.3%	2.5%	3.9%	2.5%	13.6%	2.7%
		Search costs		Search requirements		Quit rate	Human capital pdfu	
		reqc	reql	rqie				grwe
		+5%	+10%	+10%	+10%	+3% pt	-10%	-10%
Size (nr. empl)	792	123.8	800.3	736.4	806.5	622.7	758.9	666.1
Within st.dev.	44.2	2.1	38.8	32	43.6	15	37.9	26.6
Between st.dev.	93.9	0.5	82.4	100	79.8	19.1	101.9	83.1
Inflow	11.0%	9.8%	11.1%	13.2%	10.8%	24.6%	11.2%	10.7%
Internal mobility	13.0%	2.4%	13.7%	9.4%	13.8%	7.3%	11.7%	6.3%

These simulation exercises lead to the following conclusions with respect to differences between small and large enterprises:

- Small businesses react less strongly to changes in their (internal and external) environment than large enterprises do.
- Large enterprises always survive the **50-year** period of our simulations (therefore, the survival rate has not been reported in tables 7 and 8). For small businesses, this is not the case.
- Variation in firm size is always due to variation in team size (at all levels), never in number of levels. The number of hierarchical levels is determined by model parameters representing the production and management of the business, and not by the **stochastics** of the internal and external **labour** markets.
- As long as enterprises have no more than four levels, firm size shows very little variation over the simulations (4.9, 24.5 and 123 employees for 2, 3 and 4 levels, respectively). In contrast, there is much more variation in businesses with five levels (610 to 1,176 employees). This variation is ultimately caused by the variation in human capital of individual employees. Apparently, the factors that cause enterprises to become so large that their organization consists of five hierarchical levels, also enhance the relation between optimal firm size and human capital of their (incumbent) employees. This suggests that with large (**5-leveled**) firms, personnel management (hiring and selection of new employees and internal mobility of incumbent employees) and organizational changes may influence **firm** size.

With respect to the technicalities of the production process (wage costs, costs and benefits of specialization), the following conclusions emerge from the simulation experiments:

- Changes in the respective parameter values have a clear effect on the number of employees. For small businesses, the number of employees changes because a hi-

erarchical level is added or removed. For large enterprises, levels may be removed, but a sixth level is never added to the firm.

- The benchmark model of the large enterprise shows a substantial variation of average size between firms, which is caused by the heterogeneity of the labour force. Changes in the benefits and costs of specialization may, however, make the heterogeneity of employees become irrelevant again (as is the case for the small businesses). Enhancing the benefits of horizontal coordination by 2.5% results in a 48% increase of average firm size, while the between-firm standard deviation reduces **almost** to nil (table 7). A 2.5% increase of the costs of horizontal coordination lead to a 23% decrease of average size (without removing a hierarchical level), and again the between-firm standard deviation becomes very small (table 8).

With respect to the features of equilibrium search theory (search cost, requirements for candidates, quits) that are incorporated in the model, the simulation experiments of this sensitivity analysis give rise to the following conclusions:

- Search/adjustment cost have a substantial influence on the equilibrium size of the firm: increasing costs have a negative effect on the number of employees, both for small and for large enterprises.
- Factors that determine the quality requirements for internal and external candidates have a different effect on small and large enterprises: for small businesses, they influence the survival rate (and the size of the inflow), and for large enterprises, they influence the number of employees.
- The observed variation in firm size for the large enterprises depends strongly on the quit rate: if employees do not leave the company (except when retiring), the between-firm standard deviation is reduced from 93.9 to 19.1.
- An increase in the quit rate leads to a rise in direct dismissals. The underlying mechanism is that an increase in quit rate results in a rise of external recruitments. With a constant fraction of new employees being dismissed after a year (because their qualities turned out to be insufficient), an increase in external recruitments leads to a rise in outflow by direct fires.

Finally, with respect to human capital of individual employees (variation in qualities of external candidates, effects of learning by doing and company-provided training), the following conclusions are in order.

- Decreasing the available quality and/or lowering the effects of learning by doing and the returns to training has a negative effect on the *survival rates* of small businesses and on the *average size* of large enterprises.
- For small businesses, the characteristics of individual employees are negatively related with inflow (and outflow): if the average quality is higher and/or training becomes more effective, then in- and outflow rates decline. For large enterprises, the characteristics of individual employees have no effect on inflow rates.
- The relations with internal mobility are less clear for small businesses than for large enterprises. For large enterprises, there is a positive relation with internal mobility. With small businesses, both increases and decreases in the relevant model parameters seem to have a positive effect on internal mobility rates.

7. Conclusions

By using a calibrated simulation model, this paper provides a quantitative view on the importance of various determinants of the size distribution of firms. Although the model has a neo-classical background in the sense that optimal firm size is determined by profit maximizing, it combines a number of other approaches from economic literature which aim at explaining firm heterogeneity and variations in firm size. In this respect, our model pays ample attention to the various forms of transaction costs. Moreover, the model delineates external and internal labour flows; and in doing so, it shows how the performance of the firm and, therefore, its size is influenced by aspects of human capital and personnel management, such as hiring costs, firing costs, search costs, wage policy, training, job matching and setting requirements for worker qualification. In fact, our modelling exercise fully appreciates the observation by Conlisk (1996) that 'a central insight is that the existence, size, structure and workings of organizations are critically shaped by a need to economize on various transaction costs'. Our model is capable of reproducing all these insights, and the experiments with the model show the relative effectiveness of such economizing.

The sophistication of the model does not only enable us to explain size differences between enterprises of different sectors (which had already been explained by micro-economic theory) but, also, to explain why enterprises within the same sector may differ in size. The model shows that there are two sources for such size differences of firms within the same sector. The first source is differences in transaction costs that may lead, as theory predicts, to size differences between firms that operate otherwise in the same circumstances. Our simulation experiments also show that the elasticity of transaction costs - i.e. the difference in firm size evoked by a 1% difference in transaction costs - depends on firm size itself.

The second source of size differences between firms of the same sector is heterogeneity of labour supply and the reaction of personnel management on such heterogeneity. Even when transaction costs are the same for similar firms, their sizes may differ due to the qualities and qualifications of incumbent workers. The magnitude of this effect appears again to be different in small businesses and large enterprises. The relative influence that labour heterogeneity has on firm size depends crucially on the ratio between transaction costs and wage costs. In our calibrated model, small businesses with a relatively flat organization and few hierarchical levels face relatively few transaction costs, but transaction costs gain importance when the number of hierarchical levels rises and intra-firm bureaucracy increases. Therefore, the impact of labour heterogeneity (and the scope for HRM) on business performance and firm size is more severe in large enterprises than in small businesses. This conclusion is in line with Boone and van Witteloostuijn (1996), who find that the impact of human capital is more pronounced in large than in small businesses. Moreover, it is not so much the quantity of (internal) labour flows but more so the quality of these flows that matters for business performance.

Transaction cost may be categorized into coordination costs and costs of motivation. Coordination costs are indicators for the quality of management and for how well structured the organization of the enterprise is. In smaller businesses, where the owner is both entrepreneur and manager, coordination costs also relate to entrepreneurial

qualities. The model simulations show that the success and survival probabilities of new businesses depend heavily on these entrepreneurial qualities.

The specification and calibration of our model needed a number of assumptions on both the shape and parameter values of the production process and the transaction costs associated with company management. Although we have exploited as much as possible existing empirical evidence for specifying and calibrating the model, it is obvious that considerable part of the information that is crucial for the working of the model, is still lacking. E.g. much more empirical data are needed in order to come to a more robust specification of the relationship between the span of control, vertical and horizontal transaction costs and optimal team size. The sensitivity analysis of the previous section indicates that these data, and data on human capital and costs associated with hiring, firing, quitting and training, are essential for a better understanding of the reasons why profit-maximizing businesses differ in size. Collecting these data in individual case studies of enterprises seems an important scope for future research. Our modelling exercise provides a framework for the collection of these data.

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Appendix: The calibrated simulation model

In this appendix, the simulation model is described. First, the specification of the simulation model is provided, including the calibrated model parameters of the base-line simulation. Next, the marginal costs and benefits of hiring additional subordinates are derived. For the special case where all employees have the same average quality, we examine under which conditions a positive and finite team size (the profit-maximizing number of subordinates) is guaranteed.

Specification

The profit function in period t of each supervisor (occupied at hierarchical level i) is specified as:

$$prf_{it}(n_t) = \sum_{j=0}^{n_t} \{p_t a(n_t) q_{j,i+1,t} - w_{j,i+1,t} - fp_{j,i+1,t}\} - AC(n_t, n_{t-1}^*),$$

and is maximized with respect to the number of subordinates n_t (with $j=0$ to n_t an index of the subordinates). Here, n_{t-1}^* is the currently available number of subordinates.

The constituent parts are the following functions:

Production: $q_{j,i,t} = \gamma_{q,1} (\gamma_{q,2})^i c_{j,i,t}$
with $\gamma_{q,1} = 150$ and $\gamma_{q,2} = 0.85$
(loss-of-control parameter).

Small and large benchmark firms are simulated by assuming an average production of 141 and 154, respectively.

Supervision costs: $fp_{j,i,t} = \gamma_{fp,1} (\gamma_{fp,2})^i (1/c_{j,i,t})$,
with $\gamma_{fp,1} = 37.5$ and $\gamma_{fp,2} = 1$.

Cooperation: $a(n) = -\alpha n^2 + \beta n + 1$,

costs: $\alpha = 0.05625$,

Benefits: $\beta = 0.45$.

Wage $w_{j,i,t} = \gamma_{w,1} (\gamma_{w,2})^i c_{j,i,t}$,
with $\gamma_{w,1} = 175$ and $\gamma_{w,2} = 0.75$.

In this specification, the loss of control (vertical transaction costs) is incorporated in the production function. The costs of cooperation (horizontal transaction costs) and benefits of cooperation are combined into a parabolic function.

The function p_t defines the price of the output as it will be received by the firm. In our simulations, we assume a constant price: $p_t = 1$.

The relative quality measure c_{jit} is defined as:

$$c_{jit} = \text{qual}_{jt} / E(qA_{it}) \quad \text{if the job is occupied by subordinate } j, \text{ and} \\ = 1 \quad \text{if the job is vacant,}$$

where qual_{jt} is the actual quality of subordinate j , and $E(qA_{it})$ the expected quality of an external applicant.

Dynamics are incorporated in the model through the adjustment costs,

$$AC(n_t, n_{t-1}^*) = -fr_{it} (n_t - n_{t-1}^*) I(n_t - n_{t-1}^* < 0) + s_{it} \min(n_t - n_{t-1}^*, n^{int}) + se_{it} \max(n_t - n_{t-1}^* - n^{int}, 0) I(n_t - n_{t-1}^* > 0),$$

with n^{int} the number of potential internal candidates for the job (defined as the number of employees at the next lower level), and $I(\cdot)$ the indicator function. The three different search costs are:

$$\begin{aligned} \text{External search costs} & \quad se_{it} = 50. \\ \text{Firing costs} & \quad fr_{it} = 0.5 se_{it}. \\ \text{Internal search costs} & \quad s_{it} = 0.66 se_{it}. \end{aligned}$$

Both quality and age of external candidates are drawn from a uniform probability density function with upper and lower bounds that vary per level:

$$\begin{aligned} \text{Quality of applicant} & \quad qA_{it} \sim \text{UNIF}(qlb_{it}, qub_{it}), \\ & \quad qlb_{it} = \gamma_{qlb,1} (\gamma_{qprob,2})^i, \\ & \quad qub_{it} = \gamma_{qub,1} (\gamma_{qprob,2})^i, \\ & \quad \text{with } \gamma_{qlb,1} = 3, \gamma_{qub,1} = 11.6 \text{ and } \gamma_{qprob,2} = 0.87. \end{aligned}$$

Hence, expected quality is equal to $E(qA_{it}) = \gamma_{qprob,1} (\gamma_{qprob,2})^i$, with $\gamma_{qprob,1} = (\gamma_{qlb,1} + \gamma_{qub,1})/2 = 7.3$.

$$\begin{aligned} \text{Age of applicant} & \quad Age_{jt} \sim \text{UNIF}(alb_{it}, aub_{it}), \\ & \quad alb_{it} = \gamma_{alb,1} (\gamma_{aprob,2})^i, \\ & \quad aub_{it} = \gamma_{aub,1} (\gamma_{aprob,2})^i, \\ & \quad \text{with } \gamma_{alb,1} = 40, \gamma_{aub,1} = 80 \text{ and } \gamma_{aprob,2} = 0.80. \end{aligned}$$

The ‘baseline’ minimum requirements are given by:

$$\begin{aligned} mq_{it} & = \gamma_{mq,1} (\gamma_{mq,2})^i, \\ & \quad \text{with } \gamma_{mq,1} = 10 \text{ and } \gamma_{mq,2} = 0.75. \end{aligned}$$

For an internal applicant, the minimum requirements are:

$$\begin{aligned} v_{it}^{int} & = (1 + \gamma_{RQIE}) mq_{i,t}, \\ & \quad \text{with } \gamma_{RQIE} = 0.10, \end{aligned}$$

while for an external applicant, the minimum requirements equal:

$$\begin{aligned} mq_{i,t}^{ext} & = (1 - \gamma_{RQTR}) mq_{i,t}, \\ & \quad \text{with } \gamma_{RQTR} = 0.20. \end{aligned}$$

Furthermore, we have a number of functions that specify the relations between successive periods. We have a random quit probability, which is actually defined as the probability that an employee remains in the firm, $(1 - \gamma_{QUIT})^i$, with $\gamma_{QUIT} = 0.02$. There is a retirement age: an employee who reaches the age of $\gamma_{RETR} = 60$ is retired. For each worker who does not quit, we introduce an accumulation of quality, $qual_{j,t+1} = qual_{jt} (1 + 2(\frac{1}{2})^{tenJt} U)$, where U is the random factor drawn from a uniform distribution.

bution $U \sim \text{UNIF}(0, \gamma_{GRWE})$ with $\gamma_{GRWE} = 0.20$, and tenJ_i is the tenure in the current job.

Marginal costs and benefits

The optimal number of subordinates may be determined by comparing the marginal costs (mc) and benefits (mb) of hiring an additional subordinate. The marginal costs for a (potential) supervisor of hiring an (additional) subordinate are the sum of additional coordination costs, supervision costs, wage costs and adjustment costs. For a supervisor at hierarchical level (i-1) who currently employs N subordinates ($N \geq 0$), the marginal costs $mc_{i-1,N+1}$ of hiring an additional subordinate are¹⁷:

$$\begin{aligned} mc_{i-1,N+1} &= \alpha(N+1)^2 \sum_{j=0}^{N+1} q_{j,i} - \alpha N^2 \sum_{j=0}^N q_{j,i} + fp_{N+1,i} + w_{N+1,i} + AC \\ &= (\alpha N^2 + 2\alpha N + \alpha) \gamma_{q,1} (\gamma_{q,2})^i c_{N+1,i} + (2N+1) \alpha \gamma_{q,1} (\gamma_{q,2})^i \left(\sum_{j=0}^N c_{j,i} \right) \\ &\quad + \gamma_{fp,1} (\gamma_{fp,2})^i (1/c_{N+1,i}) + \gamma_{w,1} (\gamma_{w,2})^i c_{N+1,i} + AC \end{aligned}$$

The marginal benefits of hiring an additional subordinate are the sum of the benefits from the additional employee, and the changes in the benefits of the incumbent N employees. These changes are caused by changes in the benefits of cooperation if an additional employee would be hired:

$$\begin{aligned} mb_{i-1,N+1} &= (\beta(N+1) + 1) q_{N+1,i} + (\beta(N+1) - \beta N) \sum_{j=0}^N q_{j,i} \\ &= (\beta N + \beta + 1) \gamma_{q,1} (\gamma_{q,2})^i c_{N+1,i} + \beta \gamma_{q,1} (\gamma_{q,2})^i \sum_{j=0}^N c_{j,i} \end{aligned}$$

If an employee decides to become (or stay) a supervisor, then the profit-maximizing number of subordinates N^* is given by the conditions $mc_{i-1,N^*} < mb_{i-1,N^*}$ and $mc_{i-1,N^*+1} > mb_{i-1,N^*+1}$. The unique solution N^* may be found by finding the solution to $mc_{i-1,N+1} = mb_{i-1,N+1}$ (and rounding off the solution)¹⁸:

$$\begin{aligned} mc_{i-1,N+1} &= mb_{i-1,N+1} \\ \Leftrightarrow & (-\alpha N^2 - (2\alpha - \beta)N - \alpha + \beta + 1) \gamma_{q,1} (\gamma_{q,2})^i c_{N+1,i} + (-2\alpha N - \alpha + \beta) \gamma_{q,1} (\gamma_{q,2})^i \sum_{j=0}^N c_{j,i} \\ &= \gamma_{fp,1} (\gamma_{fp,2})^i (1/c_{N+1,i}) + \gamma_{w,1} (\gamma_{w,2})^i c_{N+1,i} + AC \end{aligned}$$

•

¹⁷ The time index t is removed from all equations, since it has no relevance for the calculations presented here.

¹⁸ In addition, the first derivative of the marginal costs with respect to the number of subordinates must exceed the first derivative of the marginal benefits.

Team size in firms with homogeneous employees

In the special case where all employees have the same, average quality ($c_{j,i} = 1 \forall j,i$), the equations for marginal costs and benefits become less complicated. The marginal costs equation may be simplified to:

$$\begin{aligned} mc_{i-1,N+1} &= (\alpha N^2 + 2\alpha N + \alpha) \gamma_{q,1} (\gamma_{q,2})^i + (2N + 1) \alpha N \gamma_{q,1} (\gamma_{q,2})^i + \gamma_{fp,1} (\gamma_{fp,2})^i + \gamma_{w,1} (\gamma_{w,2})^i + AC \\ &= 3\alpha \gamma_{q,1} (\gamma_{q,2})^i N^2 + 3\alpha \gamma_{q,1} (\gamma_{q,2})^i N + \alpha \gamma_{q,1} (\gamma_{q,2})^i + \gamma_{fp,1} (\gamma_{fp,2})^i + \gamma_{w,1} (\gamma_{w,2})^i + AC \\ &= \varphi_1 N^2 + \varphi_1 N + \varphi_2 \\ &\quad \text{with } \varphi_k > 0 \text{ for } k=1,2. \end{aligned}$$

The values of these parameters depend on the hierarchical level i (for notational convenience, the hierarchical level index i has been left out). Both the first-order and second-order derivative with respect to N are positive, so the marginal costs are a strict convex function of the number of incumbent subordinates.

The marginal benefits may be rewritten as:

$$\begin{aligned} mb_{i-1,N+1} &= (\beta N + \beta + 1) \gamma_{q,1} (\gamma_{q,2})^i + \beta N \gamma_{q,1} (\gamma_{q,2})^i \\ &= 2\beta \gamma_{q,1} (\gamma_{q,2})^i N + (2\beta + 1) \gamma_{q,1} (\gamma_{q,2})^i \\ &= \theta_1 N + \theta_2 \\ &\quad \text{with } \theta_k > 0 \text{ for } k=1,2. \end{aligned}$$

The marginal benefits are now increasing linearly with the number of incumbent subordinates (again, the hierarchical level index i has been left out).

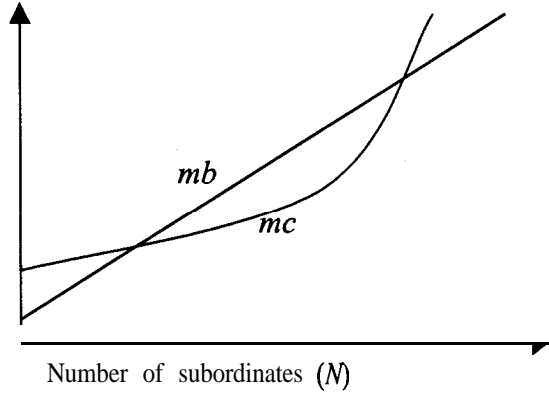
A necessary condition for a finite team size is that $mc_{i-1,N} / mb_{i-1,N} > 1$ for $N \rightarrow \infty$. This condition is always met (given that all model parameters are strictly positive):

$$\lim_{N \rightarrow \infty} \frac{mc_{i-1,N}}{mb_{i-1,N}} = \lim_{N \rightarrow \infty} \frac{\varphi_1 N^2 + \varphi_1 N}{\theta_1 N} = \lim_{N \rightarrow \infty} \frac{\varphi_1}{\theta_1} N + \frac{\varphi_1}{\theta_1} > 1$$

Whether or not an employee becomes a supervisor, depends on other criteria. A sufficient condition is that $mc_{i-1,1} / mb_{i-1,1} < 1$: the benefits of hiring the first subordinate exceed the costs. For the calibrated model, this condition is met for the first three levels of the firm. This implicates that the baseline firm should consist of at least four levels. As discussed in the main text, this is the actual number of levels for the baseline simulation. For the small business, this condition is met for the first level only, and for the large enterprise for the first three levels.

Both the small and the large enterprise have one level more than the minimum implied by the condition $mc_{i-1,1} / mb_{i-1,1} < 1$. Apparently, even if this condition doesn't hold, it may still be profitable to hire several employees. This is because marginal costs are a convex function of N , and marginal benefits a linear function (see figure 4 for an example). Necessary (but not sufficient) conditions for this solution are that $mc_{i-1,1} / mb_{i-1,1} > 1$ and $\{\partial mc_{i-1,N} / \partial N\} / \{\partial mb_{i-1,N} / \partial N\} < 1$ for $N=0$. This second inequality is equivalent with $\varphi_1 / \theta_1 < 1 \Leftrightarrow \alpha / \beta < 2/3$. This second condition is met in our calibrated model.

Figure 4 Marginal costs and marginal benefits



If the conditions that guarantee a finite number of subordinates are met, then team size is implicitly defined by the following equation:

$$\begin{aligned}
 mc_{i-1,N+1} &= mb_{i-1,N+1} \\
 \Leftrightarrow mc_{i-1,N+1} / q_{j,i} &= mb_{i-1,N+1} / q_{j,i} \\
 \Leftrightarrow 3\alpha N^2 + 3\alpha N + \alpha + \frac{\gamma_{fp,1}}{\gamma_{q,1}} \left(\frac{\gamma_{fp,2}}{\gamma_{q,2}} \right)^i + \frac{\gamma_{w,1}}{\gamma_{q,1}} \left(\frac{\gamma_{w,2}}{\gamma_{q,2}} \right)^i + \frac{AC}{\gamma_{q,1}} \left(\frac{1}{\gamma_{q,2}} \right)^i &= 2\beta N + \beta + 1
 \end{aligned}$$

Marginal benefits per unit of production only depend on the benefits of cooperation and the number of incumbent workers, and are independent of the hierarchical level i . In contrast, marginal costs per unit of production differ between hierarchical levels. In our calibrated version of the model, the relative share of the supervision costs increases with the level, while the relative weight of the adjustment and wage costs decreases.